Contact Tracing with RSSI from Raspberry Pis

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*Abstract* — I concluded

Keywords—Any keywords you think better identify your project, e.g., obstructions, orientation, detector, etc. (key words)

# Introduction

## Project Description

My project focuses on using Bluetooth signals from raspberry pis to predict the distance between the two devices when different obstructions interfered. Ultimately, with the ability to predict distance and duration of time, this project relates to piPACT’s goal of contact tracing under a private setting.

## Background Information

The devices I used are raspberry pis. For the purpose of this project, they are simply devices that advertise and scan Bluetooth signals [1]. Bluetooth signals are … [2]. Specifically, the received signal strength indicator (RSSI), a value to convey the strength of the received Bluetooth signal. Both physical and atmospherical changes in the setting affect the RSSI value [3]. The predicted distance extracted from the RSSI value is used for contact tracing, a method to identify and contact the people who have been too close to someone with a disease for too long [4].

# Hypothesis/Hypotheses

Hypothesis 1 is physical obstructions will decrease the RSSI value, thus affecting the prediction of distance. Hypothesis 2 is atmospherical obstructions will decrease the RSSI values, thus allowing for a better prediction of distance. Hypothesis 3 is that it is possible to create a detection algorithm with signals from two raspberry pis. Hypothesis 4 is putting the same obstruction on a pi will result in an insignificant difference of RSSI values as opposed to putting it on the other pi.

* All hypotheses result in being able to predict distance and duration of time which can later be used for contact tracing.
* Because the measured variable is a Bluetooth signal value, the hypotheses are directly related to Bluetooth based contact tracing.
* For hypothesis 1, the specific obstructions observed are a pair of athletic shorts, a pair of jeans, a cabinet, and a human.
* Hypothesis 2 tests the effect of temperature and humidity.
* Hypothesis 3 focuses on creating a model and algorithm that linked RSSI to distance for distance prediction.
* Hypothesis 4 tests if an obstruction affects the advertiser pi approximately equally compared to its effects on the scanner pi.

# Experiments and Data Collections

In this section, you should begin by providing a high-level overview of the experiments and data collections you executed. Subsequently, you should go into more detail on the following items. One approach might be to present this overview as a table where each row describes a distinct experiment/data collection in terms of which hypothesis it addresses, primary reason/aspect for executing it, and the number of times repeated.

1. Experiments

| Exp. # | Hyp. # | Reason | Brief Description (Temperature & Humidity were measured for all) | Rep. # |
| --- | --- | --- | --- | --- |
| 1 | 1, 2, 3 | Control | No obstructions | 44 |
| 2 | 1, 2, 3, 4 | Empircal quantification of effect | A pairt of shorts on advertiser raspberry pi | 44 |
| 3 | 1, 2, 3, 4 | Empircal quantification of effect | A pairt of shorts on scanner raspberry pi | 44 |
| 4 | 1, 2, 3 | Empircal quantification of effect | A pairt of shorts on both advertiser and scannerraspberry pi | 44 |
| 5 | 1, 2, 3, 4 | Empircal quantification of effect | A pairt of jeanrs on advertiser raspberry pi | 44 |
| 6 | 1, 2, 3, 4 | Empircal quantification of effect | A pairt of jeans on scanner raspberry pi | 44 |
| 7 | 1, 2, 3 | Empircal quantification of effect | A pairt of jeans on both advertiser and scannerraspberry pi | 44 |
| 8 | 1, 2, 3 | Empircal quantification of effect | A shelf in the middle of both raspberry pis | 39 |
| 9 | 1, 2, 3 | Empircal quantification of effect | A human body right in front of the \_\_\_\_ raspberry pi | 42 |

## Plan and Execution

I collected data by running my pis for three minutes at a distance while recording the temperature and humidity, then increasing the distance up by 3.5 inches from 0 inches to 143.5 inches. Additionally, I did measure the data when the pis were at 72 and 144 inches. For all experiments, the raspberry pis were orientated the same way. They were place in the same room, so the amount signal bouncing off surfaces should be approximately equal. They were on the floor except when they were in pockets of clothing. They advertiser pi’s TX power was consistent throughout. The varied distances were pre-measured, so the data from each variation should be at pretty equal distances.

Although changes in weather were present, they were a measured variable. …………

## Data Relevance

The goal of this project was to simulate real life situations when predicting distance from Bluetooth signals. Therefore, the physical obstructions in each experiment were chosen as they could be applied in the outside world: clothes as phones are in pockets, a cabinet like a grocery shelf or bookshelf, and human as phones could be in the back pocket. Experiments 2, 3, 5, and 6 were conducted to see whether the pi that experienced the obstruction mattered.

## Examples

Fig. 1. The comparison of the relationship between RSSI and distance for exp. 1, 4, and 7.

Fig. 2. The comparison of the relationship between RSSI and distance for exp. 1, 8, and 9.

# Analysis and Algorithms

## Description

I performed a paired t test on the experiments 2&3 and 5&6 to test hyp. 4. Specifically, I subtracted the data of exp. 3 and exp.6 from exp. 2 and exp. 5, respectively. Likewise, I performed a 2 – sample t test on all experiments and the exp. 1 to test hyp. 1.The goal of my algorithms was to ultimately be able to predict the distance of given an RSSI value, the temperature, the humidity, and the type of obstruction. Because I took upon three independent variables (distance, temperature, and humidity) at once, I created a multiple regression. In order to make the data linear, I took the log of all the x values (distance, temperature, and humidity). In order to avoid skewing the calculations too much, I removed the data at distance 0.0 inches due to the problems resulting from logging 0. From there, a regression was made to predict distance from the other three variables. Similarly, I made another regression but without temperature and humidity to test hyp. 2.

## Results and Examples

1. Statistical Significant Tests on Experiments

| Exp. # | Hyp. # | Null  Hyp. | Alt. Hyp. | t-stat. | P - value | α | df |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1, 2 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.154 | 0.561 | 0.05 | 86 |
| 1, 3 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.103 | 0.541 | 0.05 | 86 |
| 1, 4 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.485 | 0.685 | 0.05 | 86 |
| 1, 5 | 1 | μ1 = μ2 | μ1 > μ2 | 0.184 | 0.427 | 0.05 | 86 |
| 1, 6 | 1 | μ1 = μ2 | μ1 > μ2 | 0.843 | 0.201 | 0.05 | 86 |
| 1, 7 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.221 | 0.587 | 0.05 | 86 |
| 1, 8 | 1 | μ1 = μ2 | μ1 > μ2 | 0.354 | 0.362 | 0.05 | 86 |
| 1, 9 | 1 | μ1 = μ2 | μ1 > μ2 | 2.081 | 0.0206 | 0.05 | 86 |
| 2, 4 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.0131 | 0.505 | 0.05 | 86 |
| 3, 4 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.0727 | 0.529 | 0.05 | 86 |
| 5, 7 | 1 | μ1 = μ2 | μ1 > μ2 | - 0.446 | 0.672 | 0.05 | 86 |
| 6, 7 | 1 | μ1 = μ2 | μ1 > μ2 | - 1.215 | 0.886 | 0.05 | 86 |
| 2, 3 | 4 | μ = 0 | μ ≠ 0 | 0.134 | 0.894 | 0.05 | 43 |
| 2, 3 | 4 | μ = 0 | μ > 0 | 0.134 | 0.0344 | 0.05 | 43 |
| 5, 6 | 4 | μ = 0 | μ ≠ 0 | - 1.869 | 0.0685 | 0.05 | 43 |
| 5, 6 | 4 | μ = 0 | μ > 0 | - 1.869 | 0.448 | 0.05 | 43 |

Fig. 3. RSSI values for exp. 1, 4, 7, 8, and 9 against raw distance data.

Fig. 4. RSSI values for exp. 1, 4, 7, 8, and 9 against natural logged distance data.

 ŷ = -8.644ln(x) — 33.378 (1)

 ŷ = -5.12ln(x) — 47.096 (2)

 ŷ = -6.856ln(x) — 43.857 (3)

1. Proximity Predictions Soley Based on RSSI Values

| Exp. # | Model from Exp. # | True Pos. | False Pos. | True Neg. | False Neg. |
| --- | --- | --- | --- | --- | --- |
| 1 | 1 | 16 | 7 | 15 | 6 |
| 4 | 4 | 15 | 7 | 16 | 6 |
| 4 | 8 | 22 | 14 | 8 | 0 |
| 7 | 7 | 16 | 9 | 13 | 6 |
| 7 | 8 | 19 | 3 | 9 | 3 |
| 7 | 9 | 21 | 16 | 6 | 1 |
| 8 | 4 | 8 | 1 | 22 | 8 |
| 8 | 7 | 8 | 1 | 22 | 8 |
| 8 | 8 | 12 | 6 | 16 | 5 |
| 9 | 4 | 6 | 0 | 23 | 13 |
| 9 | 7 | 6 | 0 | 23 | 13 |
| 9 | 9 | 15 | 4 | 18 | 5 |

1. Proximity Predictions Based on RSSI, Temperature, and Humidity

| Exp. # | Model from Exp. # | True Pos. | False Pos. | True Neg. | False Neg. |
| --- | --- | --- | --- | --- | --- |
| 1 | 1 | 19 | 3 | 20 | 2 |
| 4 | 4 | 5 | 0 | 23 | 16 |
| 4 | 8 | 13 | 6 | 17 | 8 |
| 7 | 1 | 5 | 0 | 22 | 17 |
| 7 | 4 | 5 | 0 | 22 | 17 |
| 7 | 7 | 9 | 0 | 23 | 12 |
| 7 | 8 | 10 | 6 | 16 | 12 |
| 8 | 8 | 13 | 7 | 15 | 4 |
| 9 | 7 | 6 | 0 | 23 | 13 |
| 9 | 8 | 6 | 0 | 23 | 13 |
| 9 | 9 | 14 | 8 | 15 | 5 |

ŷ = -13.998ln(x1) —— 48.891ln(x2) + 155.880ln(x3) —— 270.694 (4)

It is apparent that in table 2, many statistical tests resulted in a large p-value compared to alpha, resulting in statistically insignificant data. Therefore, for most tested obstructions, they could all belong to the same population of data. Also, there are many instances where a model made from an experiment can be applied on the data from another experiment that will lead to the same if not better results. In this case, better results mean that there are more true positive and true negatives. Moreover, as false negatives are considered worse than false positives in this project, a significant amount of false negatives automatically is considered bad results. For instance, when temperature and humidity were taken into consideration, the data from exp. 7 resulted in the same results when put through the model made from exp. 1 and exp. 4 (table 3). Even when temperature and humidity were taken out of the picture, data from exp. 8 being put through models from exp. 4 and 7 resulted in the same numbers (table 4). Surprisingly, when the data from exp. 9 was put through 4 different models (exp. 7 & 8 made from temperature and humidity and exp. 4 & 9 made solely from RSSI values), the same numbers were outputted (table 3 & 4).. Overall, there a significant amount of false negatives when temperature and humidity are taken into account (table 4). Even though adding such conditions increase the amount of true negatives and decrease the amount of false postivies, the lack of true positves and the abundance of false negatives suggest bad results when compared to when temperature and humidity are taken out of considerence.

Figure 1 depicts the relationship between RSSI and distance. It is apparent to be a type of logarithmic function as the form is consistent, no matter the variations applied.

Equation 1, 2, and 3 are examples of the models where distance is first natural logged, then a regression line is made. They represent exp. 1, 4, and 9, respectively. Equation 1 had highest intercept and eq. 2 had the least steep slope, suggesting the it has the least intense drop at the beginning of its logarithmic curve. On the other hand, eq. 4 represents the equation for the regression line created when temperature and humidity are taken into account. Although not plotted in a figure, it is the equation for exp. 1 as x1 is distance, x2 is temperature, and x­3 is humidity.

As exp. 9 was the only experiment to be statistically significantly different from exp. 1 it is crucial to note how in both figures of this report, the line depicting that variation are constantly below all other lines, suggesting its affect on decreasing RSSI values are the most significant. As the lines from other experiments are quite similar to the line made from exp. 1, the fact that many of the experiments are not statistically significantly different from exp. 1 is confirmed.

# Conclusions

## Hypothesis Evaluation

Hyp. 1 proved to be false. Only the physical obstruction of a human resulted in statistically significant results (table 2) when compared to exp. 1. Therefore, common clothes like athletic shorts or jeans and a shelf in fact do not decrease the RSSI value. \*\*\*\*Moreover, the model of no obstruction worked as well or better … Although based on [#] atmospherical obstrucions affect RSSI in a way to help better estimate distance, based on my results, hyp. 2 proved to be false. Due to the fact that the same result were created from experiment 9 under a variation of models, atmospherical obstructions most likely do not make a significant impact on the predictions made with my data. Thus, atmospherical obstructions do not improved proximity prediction.

According to table 3, more prediction errors were made when the variables of temperature and humidity were taken into account. Hyp. 3 proved to be true. Although the algorithm is not extremely accurate, a decent algorithm was successfully created from raspberry pi signals with a success rate of …… Hyp. 4 proved to be true as table 2 shows statistically insignicant results between experiment 2 & 3 and 5 & 6. Additionally, the model of the obstruction on one pi works as well or even better when applied on the other data set.

## Noteworthy Conclusions

It seems that putting an obstruction on the scanner pi resulted in more of a decrease in RSSI value than the advertiser pi. From table 2, the test of whether the scanner pi had a larger effect was proven to be statistically significant for the obstruction jeans. Although it was not statically significant for shorts, the p value for the test of if the scanner pi has more effect was more significant than the test of if the advertiser pi has more effect. Additionally, for shorts and jeans, having one obstruction on only one pi was not statistically significant compared to having one obstruction on both pis. Adding on, due to the nature of the RSSI and distance’s relationship, it there is a sudden jump in data, it is likely to concluded that an extremely large and dense object has been placed in between two devices, or thye have suddenly approached each other and entered a dangerously close distance. Another noteworthy conclusion is that RSSI cannot reliable be used to determine proximity as there are many other factors in the specific environment needed to be taken into account.

## General Lessons Learned

Based on my results, Bluetooth-based contact tracing is not reliable in the real world as there are too many errors in predictions. Moreover, it would not be too feasible for everyone to be carrying a raspberry pi with them wherever they go as raspberry pis can not be implemnted in to all smart phones [#]. Finally, I am hesitant to believe that the Bluetooth siganls from raspberry pis are any different from the Bluetooth siganls from smartphones [#]. Therefore, raspberry pis are not efficacetic.

# Next Steps

First off, I will repeat all experiments to confirm the accuracy of my current values and to better predict proximity. Second of all, I will measure just the effects temperateur and humidity indivicaully without the effect of distance and build a model from there to better test hyp. 2. Thirdly, I’ll measure the effect of more obstructions as people do not only wear athletic shorts and jeans year-round. Specifically, I’d measure the effects of khaki shorts and long pants, winter coats, hoodies, etc… Fourthly, I would like to add on confidence intervals into my models to allow a better range for my predictions, hopefully leaing to better results. Finally, to bring this into the outside world, I will determine a method to implement Bluetooth signals from raspberry pis into a portable item for feasible use.

##### References

Insert full references here. Use whatever citation style you prefer but use it consistently. Be sure to use the appropriate template style in order for the reference list to be created properly. If using this template and MS Word, when citing references in your final report, try to use the cross-reference option in order to ensure citations are automatically updated.

1. Martin, Taylor. “How to Setup Bluetooth on a Raspberry Pi 3.” CNET, CNET, 20 May 2016, [www.cnet.com/how-to/how-to-setup-bluetooth-on-a-raspberry-pi-3/](http://www.cnet.com/how-to/how-to-setup-bluetooth-on-a-raspberry-pi-3/).
2. Franklin, Curt, and Chris Pollette. “How Bluetooth Works.” *HowStuffWorks*, HowStuffWorks, 11 Nov. 2019, electronics.howstuffworks.com/bluetooth2.htm#:~:text=Bluetooth%20networking%20transmits%20data%20via,between%202.400%20GHz%20and%202.483.&text=The%20walls%20in%20your%20house,several%20devices%20in%20different%20rooms.
3. “Factors Impacting RSSI” *Celtrio*, www.celtrio.com/support/documentation/coverazone/2.0.1/basics.rssi.html.
4. Estimote.com, et al. “How to Calculate Distance from the RSSI Value of the BLE Beacon.” *IOT and Electronics*, 7 Oct. 2016, iotandelectronics.wordpress.com/2016/10/07/how-to-calculate-distance-from-the-rssi-value-of-the-ble-beacon/#:~:text=RSSI%20is%20used%20to%20approximate,Measured%20Power%20(see%20below).&text=The%20further%20away%20the%20device,more%20unstable%20the%20RSSI%20becomes.
5. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.